

USING THE Fe/Mn RATIO OF FeO-RICH OLIVINE IN WILD 2, CHONDRITE MATRIX, AND TYPE IIA CHONDRULES TO DISENTAGLE THEIR HISTORIES. D. R. Frank¹, M. E. Zolensky², and L. Le¹,
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Introduction: The Stardust Mission returned a large abundance of impactors from Comet 81P/Wild2 in the 5-30 μm range. The preliminary examination of just a limited number of these particles showed that the collection captured abundant crystalline grains with a diverse mineralogy [1,2]. Many of these grains resemble those found in chondrite matrix and even contain fragments of chondrules and CAIs [1-3]. In particular, the olivine found in Wild 2 exhibits a wide compositional range ($\text{Fa}_{0.97}$) with minor element abundances similar to the matrix olivine found in many carbonaceous chondrites (CCs) and unequilibrated ordinary chondrites (UOCs). Despite the wide distribution of Fa content, the olivine found in the matrices of CCs, UOCs, and Wild 2 can be roughly lumped into two types based solely on fayalite content. In fact, in some cases, a distinct bi-modal distribution is observed.

FeO-poor. Forsterite with wt.% FeO ~ 15 exhibits a wide range of the minor elements Mn, Cr, Ca, and Al, with the extent of their ranges generally increasing with decreasing Fe content. Some of our analyses of these grains overlap the compositional fields defined by type I chondrules and others do not. We suspect that some of these grains are fragments of type I chondrules and some are more primitive condensates from a nebular gas. However, disentangling the origins of these grains will require a more detailed investigation. Here, we focus on the second group.

FeO-rich. Olivine with wt.% FeO $\sim 18-20$ is found in the matrices of most unequilibrated chondrites (excepting Kakangari and enstatite chondrites). It has been noted by [4,5] that the Fe content of olivine found in UOC, CO, and CR type IIA chondrules is strongly correlated with Mn. Additionally, [6,7] (and references contained therein) have shown that isolated FeO-rich olivine grains in the matrices of UOCs and CO chondrites have Fe/Mn trend lines that directly overlap those of the type IIA chondrules, and provide other convincing arguments that these grains are chondrule fragments. However, the definition of a “matrix grain” in these studies is ill defined and in some cases includes isolated grains that reach 300 μm . In our study, we apply the Fe/Mn systematics of FeO-rich olivine to Wild 2 and other chondrite varieties. In addition, we have strictly limited our analyses to the matrix olivine 5-30 μm found in the least equilibrated chondrites (petrographic grade 3.0 or less), since these are the best

available analogies to the grains found in the Wild 2 collection.

Samples and Methods: We present EPMA analyses from Murchison, Mighei, Maribo, El-Quss Abu Said, and Kivesvaara (CM2), MET 00426 and QUE 99177 (highly unaltered CRs), ALHA 77307 (CO 3.0), Kaba and Bali (CV 3.0), Semarkona (LL3.0), as well as the C2 ungrouped chondrites Acfer 094 and Bells. We are also being allocated two TEM grids from each Wild 2 particle that has been harvested from the Stardust aerogel collectors and subsequently microtomed. To date, we have performed TEM/EDXS measurements on 22 particles harvested from 14 tracks.

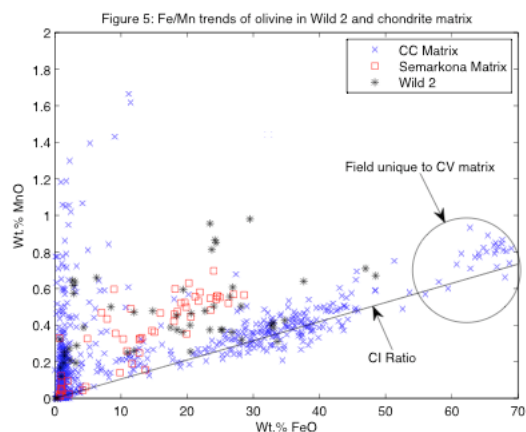
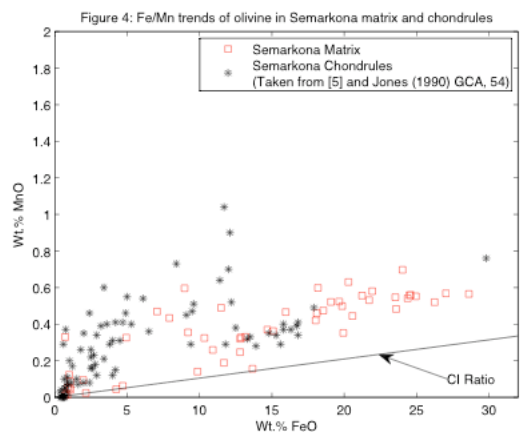
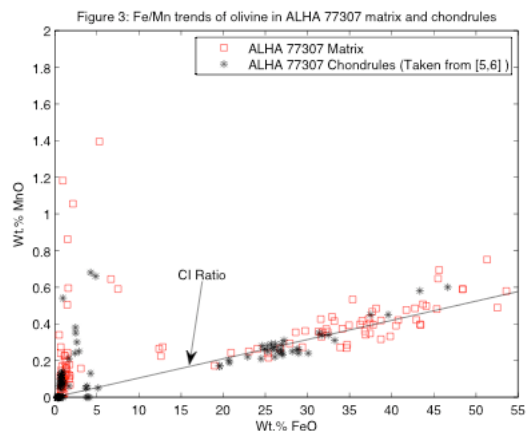
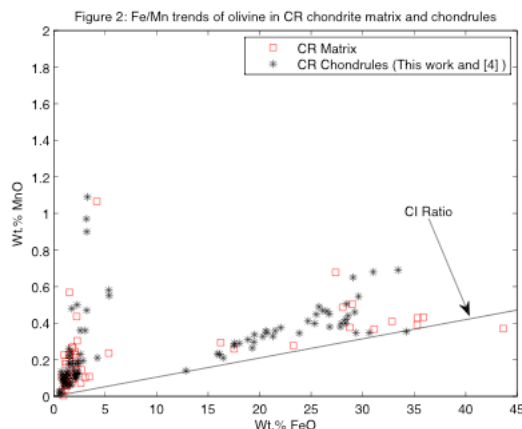
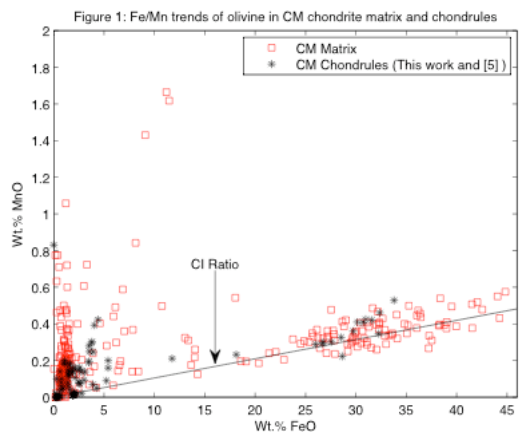
Results: Despite varying petrographic grades and ranges of fayalite content, we find that all of the FeO-rich olivine in our samples in both matrix and type IIA chondrules is linearly correlated with Mn. Figs. 1-4 show these trends for CM, CR, CO, and Semarkona. Before comparing to Wild 2, we think there are two major observations to be made.

Fractionation from the CI bulk abundances. FeO-rich olivine in the matrices of CM, CO, and the ungrouped C2 chondrites Bells and Acfer 094 all follow very nearly the same linear Fe/Mn trend. The Fe/Mn ratio calculated by linear regression of this trend is 88.75, close to the CI bulk abundance of 94.24 calculated by [8]. A direct implication is that the C2 aqueous alteration apparently had negligible impact on the Fe/Mn ratio of surviving olivine grains. In CRs and CVs, the average Fe/Mn ratio appears to be slightly less relative to the aforementioned CCs. However, the CR analyses still overlap the field defined by them. The CV matrices, however, include $\text{Fa}_{74.99}$ that is not found elsewhere. Semarkona is even more enriched in Mn and its olivine compositions are distinct.

Matrix vs. type IIA chondrules. In each chondrite class except the CVs, our analyses of FeO-rich matrix olivine directly overlap those of type IIA chondrules (fig. 1-4). Additional analyses of CVs may demonstrate a similar pattern although it is not observed with our present data. Many of these grains are angular and we conclude that most, if not all, of them are type IIA chondrule fragments. However, the matrix grains extend to higher FeO content than the chondrules while following the same trend. Since olivine with a higher FeO content melts at a lower temperature, the presence of these grains cannot be explained as chondrule precursors. A direct corollary, then, is that more FeO-rich

type IIA chondrules probably once existed and were preferentially disaggregated into matrix before and/or during accretion. This is consistent with the fact that forsterite has a higher tenacity than fayalite [9], since increasing FeO content increases olivine brittleness.

Conclusion: Since all of the FeO-rich olivine in CC matrix (except CVs) spans the same field, we have plotted these together in fig. 5. We see that some of the FeO-rich olivine in the Wild 2 collection directly follows the Fe/Mn trend of CCs, while some directly follows the trend of Semarkona. In addition, we have one anomalous grain of Fa_{97} (not shown here) that is extremely enriched in Mn (up to 5.1 wt.% MnO). As far as we know, this composition is unique to Wild 2. Its origin, of course, is highly uncertain, but perhaps it represents a condensation process unique to the Kuiper Belt. Thus, the view we are beginning to adopt is that the FeO-rich olivine in Wild 2 is primarily a mixture of type IIA chondrule fragments that were radially transported from CC and ordinary chondrite forming regions. However, the absence of Fa_{74-99} in Wild 2 that fits the CC Fe/Mn trend implies that Wild 2 did not receive a significant contribution from CV material. In addition, Wild 2 appears to contain rare grains that originate from the outer solar nebula.



References: [1] Zolensky M. et al. (2008) *Meteoritics & Planet. Sci.*, 43, 261-272. [2] Zolensky M. et al. (2006) *Science* 314, 1735-1740. [3] Nakamura T. et al. (2008) *Science*, 321, 1664-1667. [4] Berlin J. et al. (2011) *Meteoritics & Planet. Sci.*, 46, 513-533. [5] Brearley A. and Jones R. (1998) *Rev. Mineral.*, 36, 3-01-3-398. [6] Jones R. (1992) *GCA*, 56, 467-482. [7] Brearley A. (2011) *Chondrules and the Protoplanetary Disk*, 15, 137-149. [8] Anders E. and Grevesse N. (1989) *GCA*, 53, 197-214. [9] Deer, Howie, and Zussman (1982) *Rock Forming Minerals*, 1A, 187.

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